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**(54) Electromagnetically driven
tuning fork for determining fluid
properties**

(57) An instrument for sensing a characteristic of a fluid by its effect on a vibrating tuning fork exposed in the fluid comprises a non-magnetic wall (4) forming in use a boundary to the space occupied by the fluid; a W-shaped magnetic yoke the three legs (1,2) of which extend through the wall in use into contact with the liquid with the base part of the W on the outside of the wall; the end of the central leg (2) being bifurcated to form tuning fork tines (3) each spaced from, and facing in its direction of vibration, a

respective adjacent one of the outer legs; and a coil (5) associated with the base part of the W and arranged to be energized with an oscillating electrical current whereby periodic magnetic flux (6) is produced in the yoke to cause the tines to be vibrated as a result of the periodic magnetic attraction between each tine and the adjacent outer leg. A piezoelectric crystal detector (7) is connected to the base of the yoke to sense oscillation of the tuning fork. Associated circuitry is connected to the coil (5) and detector (7) to derive the density, viscosity, or the presence or absence of particular fluids from the resonant frequency of vibration or the attenuation in the vibration of the tuning fork.

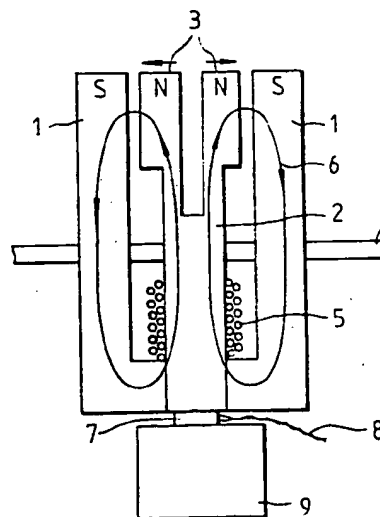


Fig.1

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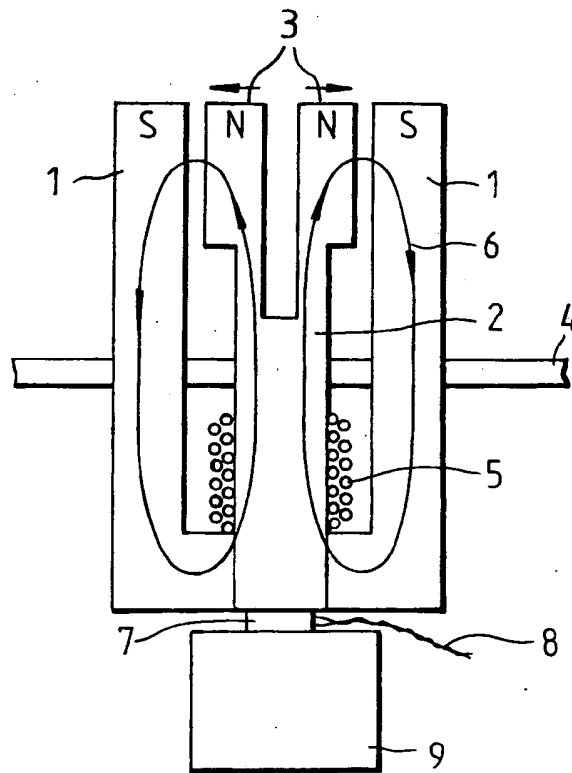


Fig. 1

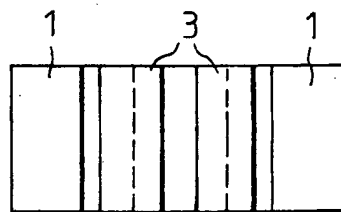


Fig. 2.

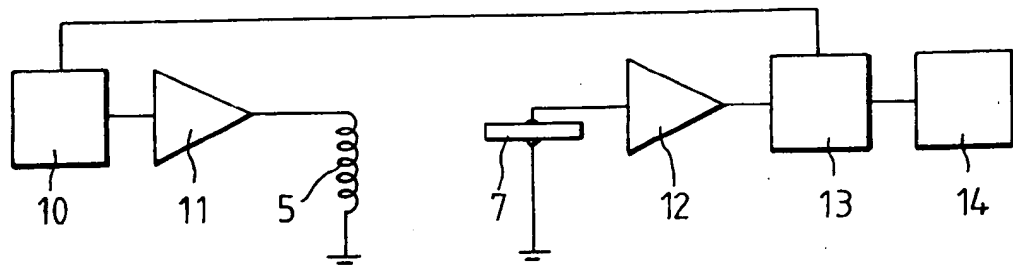


Fig. 3.

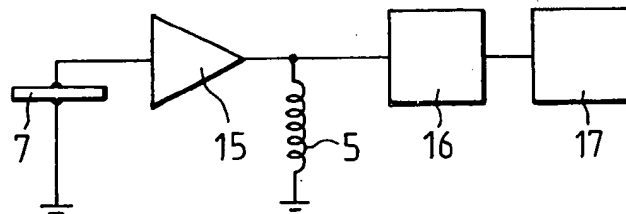


Fig. 4.

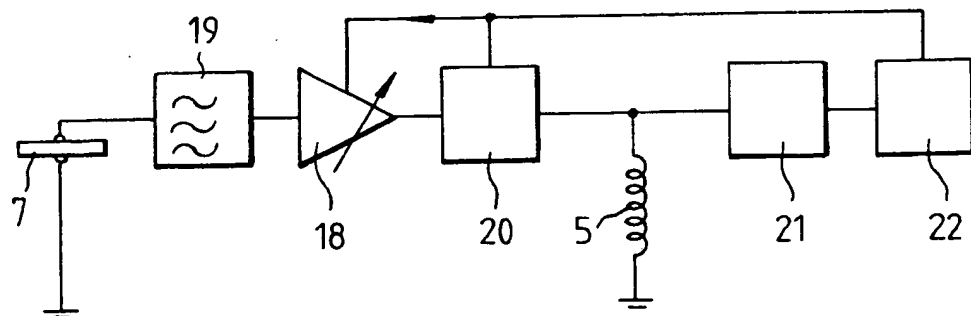


Fig. 5

SPECIFICATION

Fluid sensor

There has recently been proposed an instrument for measuring the density of a liquid, the instrument comprising a tuning fork which is immersed in the fluid and the tines of which are caused to vibrate. The fluid provides a mass loading effect on the vibrating tines and the resonant frequency of vibration is dependent upon the density of the fluid. The effect is particularly marked when the tines of the tuning fork are closely spaced and wide in the transverse direction perpendicular to their direction of vibration.

The tines of one such instrument have been vibrated by means of a magnetic core which is surrounded by a coil carrying an oscillating electrical current, and which is positioned adjacent to a pole piece of magnetic material carried on the outer face of each tine. However, this involves mounting of the cores and coils within the fluid space and this is inconvenient as it requires protection for the core and coils from the fluid, a mounting within the fluid for the cores and coils, and additional sealing where the electrical connections to the coils pass through the boundary wall of the fluid space.

In accordance with the present invention, an instrument for sensing a characteristic of a fluid by its effect on a vibrating tuning fork exposed in the fluid comprises a non-magnetic wall forming in use a boundary to the space occupied by the fluid; a W-shaped magnetic yoke the three legs of which extend through the wall in use into contact with the liquid with the base part of the W on the outside of the wall; the end of the central leg being bifurcated to form tuning fork tines each spaced from, and facing in its direction of vibration, a respective adjacent one of the outer legs; and a coil associated with the base part of the W and arranged to be energised with an oscillating electrical current whereby a periodic magnetic flux is produced in the yoke to cause the tines to be vibrated as a result of the periodic magnetic attraction between each tine and the adjacent outer leg.

This construction is simple and not susceptible to failure as only the ends of the three legs of the yoke have to pass through the boundary wall to which they can readily be sealed. The coil is mounted on the dry side and the energy for vibrating the tuning fork tines passes along the yoke through the boundary wall as an oscillating magnetic flux, and not as a mechanical oscillation which might promote failure of the seals between the yoke legs and the wall. The tines are vibrated as a result of the periodic attraction between the effective pole pieces adjacent to the ends of the tines and the adjacent ends of the outer legs, thereby utilizing a maximum moment arm in the flexure of the tines. The electrical energy for promoting the vibration can thus be minimised.

The coil may be wound on one of the three legs, preferably on the central leg, or on a web

portion of the base part of the yoke extending transversely between and interconnecting the central leg with one of the outer legs.

If the instrument is to be used for measuring the density of the fluid, usually a liquid, it will be necessary to determine the resonant frequency of the tuning fork exposed in contact with the liquid. This may be achieved by means of a piezoelectric crystal, or other detector, fitted to the base or other part of the yoke and responsive to the frequency of vibration of the tuning fork tines. The energizing frequency may then be caused to sweep through a range of frequencies and the peak response, corresponding to the resonant frequency, obtained from the detector.

Alternatively the electrical output from the detector may be fed back through a positive gain amplifier to energize the coil, so that automatic resonance is obtained, and the resonant frequency determined.

In alternative applications the instrument may be used for determining the viscosity of the fluid. The fluid will tend to dampen the oscillation of the tuning fork tines and this can be sensed by the energy requirement to maintain the tuning fork oscillating resonantly. In practice this may be achieved by determining the gain necessary in the previously described automatic resonant feedback circuit to maintain oscillation.

The instrument could of course be used as a level sensor, for example for measuring the presence or absence of liquid at a level in a container at which the instrument is fitted. All that would then be necessary would be for the instrument to be able to discriminate between the resonant frequency or attenuation of the vibrating tuning fork when the tines are immersed in liquid and air.

An example of an instrument constructed in accordance with the present invention is illustrated diagrammatically in the accompanying drawings, in which:—

Figure 1 is a plan;

Figure 2 is an end elevation on the wet side; and,

Figures 3, 4 and 5 are alternative circuit diagrams.

As shown in Figures 1 and 2, the instrument comprises a W-shaped yoke made of magnetic stainless steel, outer legs 1 of which form pole pieces and a central leg 2 of which forms a tuning fork. The free ends of the pole pieces and tines 3 of the tuning fork formed by the bifurcated end of the leg 2, are, as shown in Figure 2, appreciably elongate in the direction perpendicular to the plane of Figure 1. The construction is symmetrical about the central plane between the tines of the tuning fork. The separation of the tines is substantially twice that of the separation of the outer face of each tine from the adjacent pole piece.

The three legs of the yoke extend through and are sealed to a non-magnetic stainless steel wall 4, which separates the wet side (above the wall in Figure 2) from the dry side, and which may be

part of a container for the fluid. During assembly the base part of the yoke may be welded up after insertion of the legs through the wall, or the wall may be assembled in pieces between the legs and welded up.

5 A coil 5 is wound on the root of the central leg and develops in the yoke a magnetic flux 6. The flux induces opposite poles at the end of each pole piece and at the end of the adjacent tuning fork tine respectively so that the two are attracted. When the coil is energised with an oscillating current, the periodic attraction causes the vibration of the tines.

15 A piezoelectric crystal detector 7, from which an output is taken through leads 8, is interposed between the base of the yoke and a counter-weight 9.

Figure 3 illustrates the application previously referred to for measuring the density of a fluid, particularly a liquid, by determining the resonant frequency of the tuning fork exposed in contact with the fluid. The drive coil 5 is energized by a frequency sweep generator 10 via an amplifier 11. The output of the crystal detector 7 is fed via an amplifier 12 to a frequency measurer 13 from which the necessary calculation and display is derived in a unit 14.

Figure 4 illustrates the alternative arrangement for measuring density, in which the electrical output from the crystal detector 7 is fed through a positive gain amplifier 15 to energize the drive coil 5 so that automatic resonance is obtained, the resonant frequency being recognised by a frequency measurer 16 which feeds a calculation and display unit 17.

Figure 5 shows the use of the instrument for determining the viscosity of a fluid, particularly a liquid. Thus the automatic feedback circuit of Figure 4 is modified by substituting a variable gain amplifier 18, for the positive gain amplifier 15 optionally with the interposition of a filter 19. The signal amplitude is measured by the unit 20. The resonant frequency is again measured by a unit 21 and the gain necessary to maintain oscillation is calculated and displayed by the unit 22.

Any of the illustrated circuits could be used when the instrument is adapted for use as a level sensor. As previously mentioned, it is only necessary for the calculation and display unit to discriminate between the resonant frequency or gain, which represents attenuation of the vibrating tuning fork, when the tines are immersed in different fluids, particularly liquid and air.

Claims

1. An instrument for sensing a characteristic of a fluid by its effect on a vibrating tuning fork

exposed in the fluid, the instrument comprising a non-magnetic wall forming in use a boundary to the space occupied by the fluid; a W-shaped magnetic yoke the three legs of which extend through the wall in use into contact with the liquid with the base part of the W on the outside of the wall; the end of the central leg being bifurcated to form tuning fork tines each spaced from, and facing in its direction of vibration, a respective adjacent one of the outer legs; and a coil associated with the base part of the W and arranged to be energised with an oscillating electrical current whereby a periodic magnetic flux is produced in the yoke to cause the tines to be vibrated as a result of the periodic magnetic attraction between each tine and the adjacent outer leg.

2. An instrument according to claim 1, in which the coil is wound on one of the legs of the yoke.

3. An instrument according to claim 1 or claim 2, in which a detector is fitted to the yoke and is arranged to be responsive to the frequency of vibration of the tuning fork tines.

4. An instrument according to claim 3, in which the detector is a piezoelectric crystal detector fitted to the base of the yoke.

5. A fluid density measuring instrument according to claim 3 or claim 4, wherein the coil is energized by a frequency sweep generator and means are coupled to the detector for determining the peak response, corresponding to the resonant frequency of the tuning fork.

6. A fluid density measuring instrument according to claim 3 or claim 4, wherein means are provided for feeding an electrical output from the detector back through a positive gain amplifier to energize the coil, so that automatic resonance is obtained, and means are provided for determining the resonant frequency.

7. A fluid viscosity measuring instrument according to claim 3 or claim 4, wherein means are provided for sensing the energy requirement to maintain the tuning fork oscillating resonantly.

8. An instrument according to claim 7, wherein means are provided for feeding an electrical output from the detector back through a variable gain amplifier to energize the coil, and means are provided for deriving the viscosity from the gain necessary for maintaining oscillation of the tuning fork.

9. A level sensing instrument according to claim 3 or claim 4, wherein means are provided for discriminating between the resonant frequency or attenuation of the vibrating tuning fork when the tines are immersed in different fluids.

10. An instrument substantially as described with reference to any one of the modifications illustrated in the accompanying drawings.

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